

SOME OPTIONS FOR A MINIMUM SOLAR PROBE MISSION

J. B. Randolph, B. "J." Tsurutani, P. R. Turin, R. M. Miyake, and J. A. Ayon
(Jet propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA USA 91109)

Abstract

Smaller and lower cost options of NASA's Solar Probe mission have recently been studied. The difference between these options and the results of earlier studies is dramatic. The motivation for low cost has encouraged the JPL design team to accommodate a smaller scientific payload using innovative multi-functional subsystems. The thermal shield that is synonymous with a close solar mission has been dramatically redesigned to provide multiple functions of shielding, communications, and (on some options) science instrument accommodation. Other new concepts to support the science include a deployable mirror for remote sensing, and a boom mounted platform for a plasma spectrometer (on some options) that will provide a nearly spherical field-of-view for the instrument. The options demonstrate that high performance systems can be designed to accomplish the mission within highly constrained mass, power, and costs.

Introduction

During the past two years a series of spacecraft and payload options have been developed for the Solar Probe mission (Ref. 1). These options reflect evolving science requirements and payloads, as well as a more clear understanding about how the spacecraft would accommodate these payload changes. Also, an instrument technology development program is under way that has already suggested new smaller instrument concepts that could be incorporated in the spacecraft. The goal of the LowCS (size, mass and cost concept) was paramount to the studies that were undertaken. Miniaturization in spacecraft components and the incorporation of a parabolic shield antenna concept has led to the current spacecraft design that can be launched on a Delta vehicle directly to Jupiter providing a short flight time to the sun from a relatively inexpensive vehicle. The same spacecraft can also be a partner with the Russian "Plamya" spacecraft (Ref. 2) on a Proton launch if the joint FIRE program with the Russians is accomplished. Either launch would occur in 2003 for an arrival at Perihelion of 2007.

Mission Description

Figure 1 illustrates the Solar Probe trajectory near the sun as viewed along the line to the earth. Two trajectories are shown: the U.S. Solar Probe trajectory having a perihelion radius R_p of 4 Solar Radii (R_s) and the Plamya trajectory with an R_p of $10R_s$. Both trajectories are plotted over a model of the magnetic field of the sun from Ref. 3 that illustrates the nearly radial "open" field lines above the polar regions of the sun and the "closed" field lines that occur above the lower latitude regions. Some key design issues can be seen in the figure. First, the proximity to the sun requires a unique spacecraft thermal control solution because the thermal flux at the sun is over 400 w/cm^2 suggesting that a thermal shield is necessary if the spacecraft components are to be maintained at room temperature. The elliptical appendage on the Solar Probe in Figure 1 that is always nadir pointed is the (her-ma) shield. It is also a parabolic antenna that has an elliptical outer edge

and is tilted at an angle to the spacecraft-sun line to cast a nearly circular shadow. Or umbra over the spacecraft. The perihelion geometry has been designed to allow the perihelion to occur when the spacecraft-earth line is exactly Perpendicular to the trajectory plane or in astronomical terms, when the spacecraft is in "quadrature" with the earth which has two important consequences. First, the off-axis antenna boresight of the antenna/shield can always point at the earth during the entire nadir pointing maneuver. That is the rotation axis of the spacecraft is parallel to this antenna boresight (out of the plane of the figure). This allows continuous communications to the earth near perihelion from an antenna that has the highest possible gain given other size constraints.

Another consequence of this geometry has to do with the requirement for the high telecommunications performance, given two communications problems near the sun. First, at perihelion the sun will be in the side lobes of the antenna beam of the ground tracking station. With the quadrature geometry, the angle between the sun and the spacecraft is maximized; in this case it is about 1 degree. This maximum separation angle is necessary to minimize the "hot noise" input to the ground receiver that reduces the reception performance of the station. Secondly, it is well known that the solar corona is a perturbation source on any radio signal that passes through it. Again, the quadrature geometry allows the spacecraft to be as far as possible from the sun (and its corona) to minimize the effects of these coronal perturbations. Even with these advantages, the degradation in telecommunications performance of the Solar Probe near the sun is significant. Analysis (Ref. 1) suggests that the reduction in telemetry rate caused by the proximity to the sun is at least an order of magnitude during 10 hours around perihelion. The large parabolic shield optimizes the Solar Probe telecommunications performance because it provides a very large (1.5m x 3m) and high gain (approximately 41 dB) antenna to compensate for these losses caused by the proximity to the sun while minimizing the transmitter power. The Plasma spacecraft will have significantly higher telemetry rates because of its larger distance from the sun and reduced scintillation effects, even though its antenna is just 1 meter in diameter (see Fig. 1) to fit within the umbra of the Plasma shield.

A third issue that can be inferred from Figure 1 is that of solar wind aberration. Note that when the Solar Probe is in the polar regions (e.g. between -6 and -8 hours in the figure), the solar wind direction (along the magnetic field lines) is almost radial from the sun. Also, it is thought to have a very high velocity (>600 km/sec) in these regions (Ref. 3). At that same time the velocity of the spacecraft is about 200 km/sec. Thus, as viewed from the spacecraft the wind is coming from the near nadir direction. The measurement of this polar wind was considered to be a high priority goal during the Minimum Solar Mission (MSM) study in 1995 (Ref. 3). In the equatorial region near perihelion; the wind velocity is lower (~300 km/sec), the field is not radial, and the spacecraft velocity is higher (~300 km/sec). Thus, there is an aberration of the solar wind and it appears to be coming from the side of the spacecraft and not from the nadir direction. This is important for instrument viewing constraints discussed below.

New Science Requirements

Recent new data acquired by the Ulysses and other missions has changed the requirements for the Solar Probe mission by emphasizing two new issues. First, the confirmation of the high speed solar winds over the polar corona holes makes it imperative to investigate this region with in-situ instrumentation close to the sun. A required product of this investigation is a spherical distribution function of the particles and ions. This function can yield valuable information about the acceleration processes of the solar wind near and below the spacecraft (see Ref. 3). Viewing the high speed winds implies plasma instrument viewing capabilities in the nadir direction. Thus, the instruments would either have to look

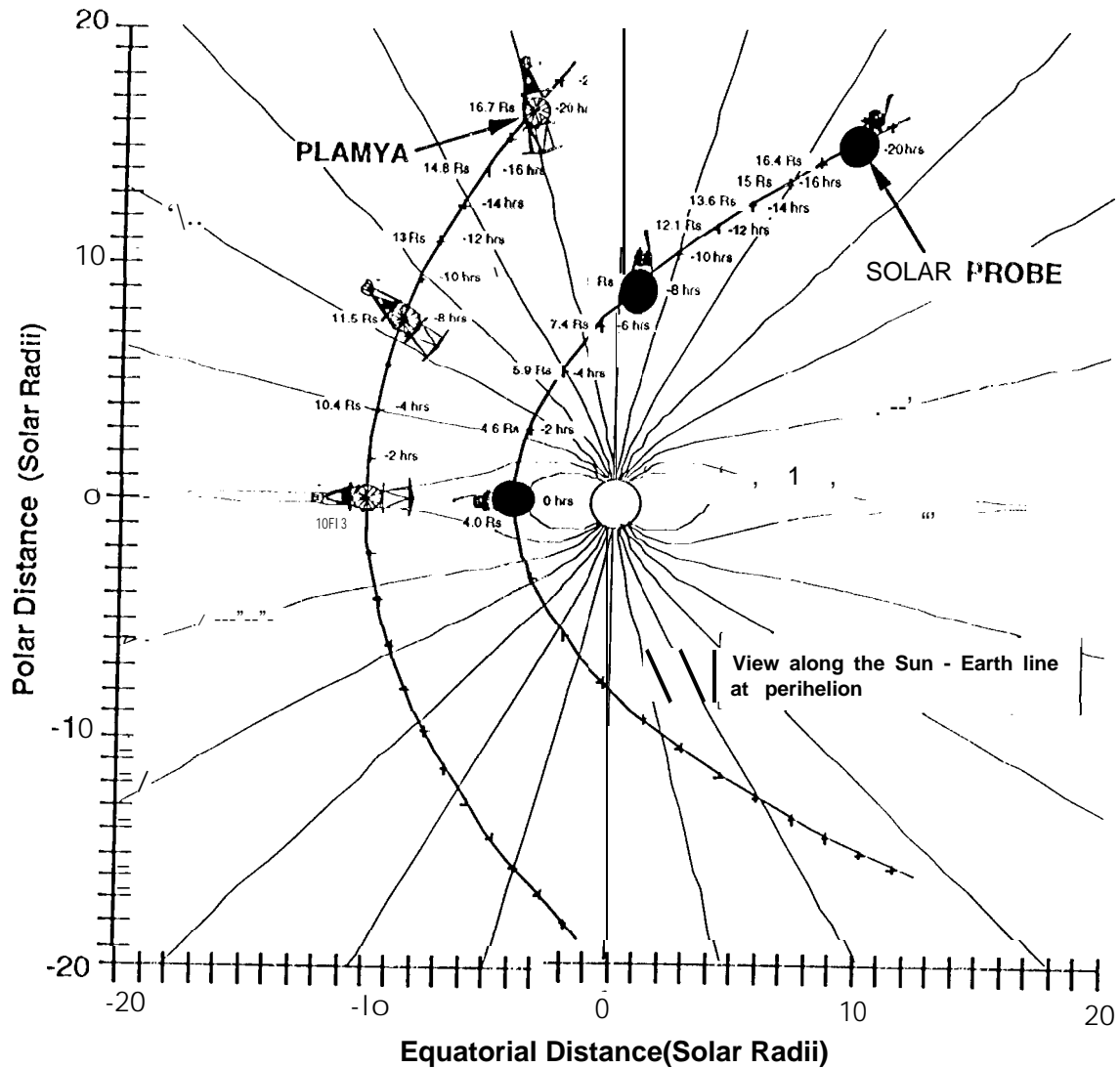


Figure 1 Perihelion Trajectories for the Solar Probe and Plamya Missions

through or around the primary shield as discussed later for the new spacecraft concepts. in addition, recent recommendations from the Solar Probe Science community (Ref. 4) have suggested that much higher downlink data rates are required to capture the highly variable characteristics of the distribution functions near perihelion. Given the extreme constraints on telecommunications performance (Ref. 1), [his may require new techniques for on-board analysis (e.g., data compression) to allow high rate data acquisition but low rate data transmission.

Secondly, there has been a renewed interest (Ref. 3) in imaging the solar "surface" from the Solar Probe to observe the small active regions within the sun's photosphere that are predicted by certain models to be source regions for the solar wind. This nadir viewing implies a spacecraft capability to somehow look around (or through) the spacecraft's primary shield and is a new challenge for the spacecraft system. Various techniques

proposed to accomplish this viewing will be discussed below in the context of the spacecraft concepts that have been studied.

Recent Spacecraft Concepts

in a recent paper (Ref. 4), the history of Solar Probe design concepts was reviewed. The evolution from large Galileo class spacecraft to current lightsat class spacecraft has been significant. In this paper, we will review only the most recent Solar Probe concepts in the context of their scientific instrument accommodation. Figure 2 is a summary of the three recent design concepts since 1994. The upper figures illustrate the "front" views of the concepts looking along the antenna boresight line and the lower figures represent the isometric views of each concept. Instrument accommodation for each concept is discussed in the following paragraphs.

The 1994 Solar Probe Configuration

Typical of the recent configurations (before the new science emphasis on polar winds), the 1994 Solar Probe configuration in Figure 2a allowed science instruments to view only in the direction of the aberrated solar winds near the equatorial region (see discussion related to Figure 1). The instruments were located in the center of the umbra and had apertures viewing to the sides of the spacecraft as shown in the upper figure. A fixed length boom allowed the magnetometer instrument to be located near the tip of the perihelion umbra as shown in figure 2a. The parabolic shield/antenna had reasonable telemetry rates of about 4 kilobits/sec at perihelion supporting the 17 kg payload described in Ref. 5.

The 1995 MSM Configuration

A significant departure from the 1994 configuration was developed in support of the Science Definition Team in 1995 during their study of a Minimum Solar Mission (Ref. 3). They recommended nadir viewing for both plasma and optical instruments. In order to accommodate these new instrument requirements, the shield/antenna was reshaped to have a conical surface (or "bustle") for the lower half of its area (see the lower Figure 2b). The shield then extended to one side of the spacecraft allowing instrument apertures through the conical shield section for optical and plasma observations in the nadir direction as shown in the upper Figure 2b. Although the science instruments could now view in the nadir direction, there remained some open issues as to the operability of those apertures. There could be scattering problems in the aperture tubes of the optical instruments (see Figure 2b) that could cause unfocused images. The holes in the shield for the plasma instrument could be sources of residual fields that would deflect (at least low energy) particles as well as causing possible ablation sources that could be dangerous to the survival of the shield. In addition, the conical section in the shield reduces the effective radiating area as an antenna thereby reducing the gain of the antenna (and the downlink telemetry rate).

The 1996 Configuration

In response to the above issues about the "bustle" shield, an updated concept was developed that removed the bustle and the continuous nadir viewing capability for the science instruments. It was recognized in the MSM study (Ref. 3) that continuous nadir imaging was not necessary because the scene changed slowly. Thus, the idea of periodic nadir imaging suggested that an instrument, that could look around the shield in the nadir direction (but only periodically), was a viable alternative to the MSM imager. In addition,

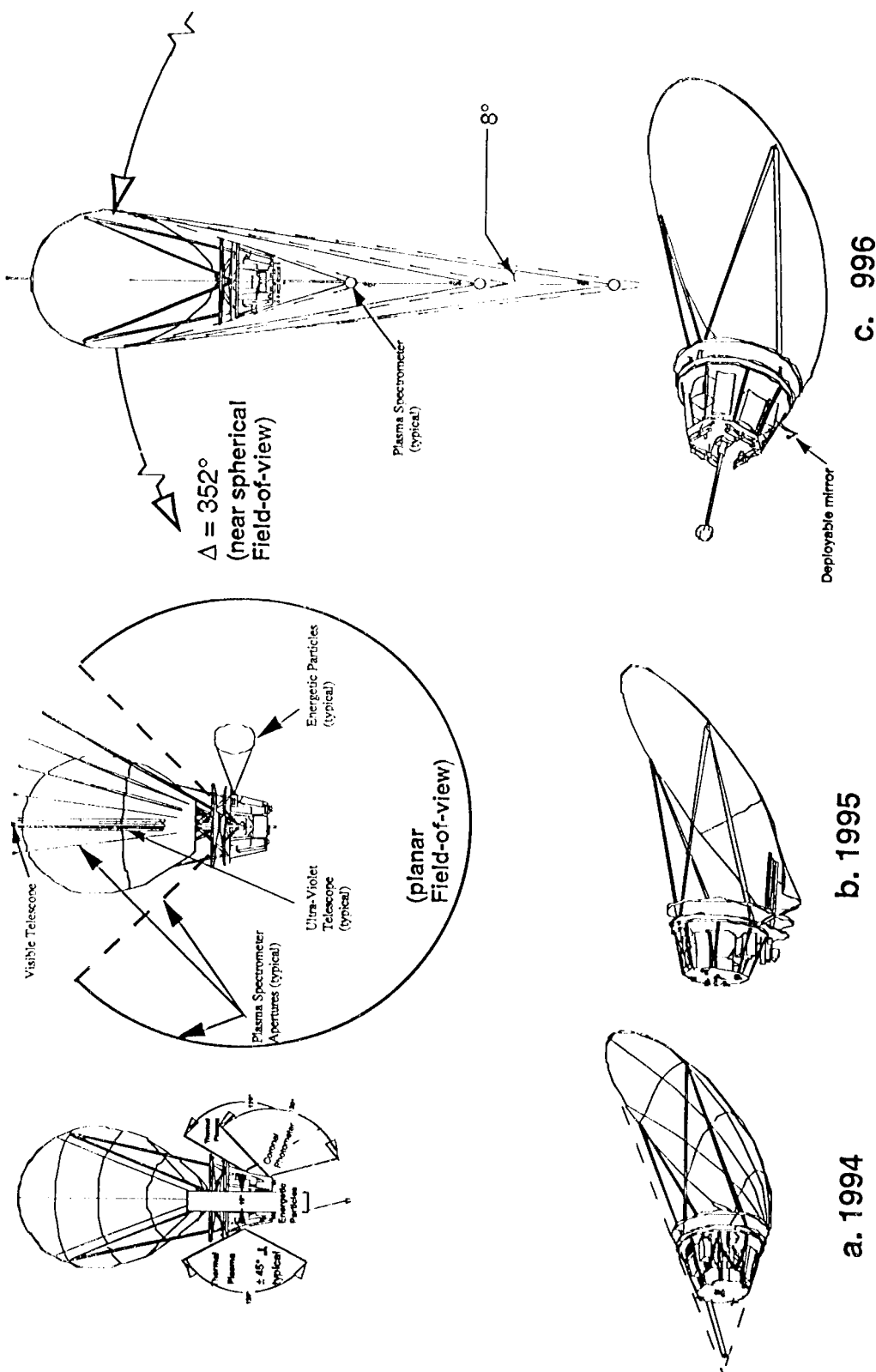


FIGURE 2 Recent Solar Probe Configurations with Instrument Fields-of-View

an image! such as this could be self Contained as a relatively independent element without affecting the overall thermal and structural design of the spacecraft system. A mirror concept (Ref. 1) as shown in the lower Figure 2c could be thrust out of the umbra by an extensible arm, remain there for a few tenths of a second (allowing the required imaging exposures of a few milliseconds), and retract into the umbra. This sequence could be repeated every 10 minutes (to allow thermal recovery) to provide disk imaging with that time interval. This concept depends on a mirror design that can tolerate the extreme solar flux (about 3000 suns) for the short exposures to sunlight. A transparent quartz mirror would suffice for the visible (magnetograph) imaging but some other type of mirror would be necessary for the EUV viewing.

In an attempt to satisfy the viewing requirements of the plasma instrument, an instrument with a spherical field of view was placed on an extendible boom that would locate the instrument always at the lip of the conical umbra near perihelion as shown in Figures 2c. As the spacecraft approaches perihelion and the umbral cone gets shorter as shown in the upper figure, the boom is retracted far enough to keep the instrument just within the umbra. This allows the smallest possible viewing angle (e.g. 8 degrees) toward the nadir direction without having apertures in the shield.

Figure 2 compares the viewing angles for the three recent concepts. Note that the MSM configuration has limited but continuous nadir viewing in discrete directions in a plane through the holes in the shield. The plasma instrument would view through the holes at these discrete angles and then in a 360 degree pattern in the same plane. However, even though the 1996 configuration views only within 8 degrees of nadir (over the solar poles), it has a spherical field of view that can capture data out of the plane that would be obscured in the MSM configuration.

Conclusion

In conclusion, the latest configuration retains the advantages of the parabolic antenna/shield and its full telecommunications performance while allowing periodic nadir viewing for imaging and near-nadir continuous viewing for a spherical field-of-view plasma instrument. A review of the trades between various configurations is scheduled for later in 1996 when a new NASA Science Definition Team will be convened to evaluate the science-spacecraft issues leading to a refined baseline concept for the Solar Probe mission.

Acknowledgment

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